Power aware stability-based routing protocol for hybrid ad hoc networks

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Abstract: Energy efficiency is an important design consideration in hybrid ad hoc network due to the limited battery life of mobile terminals. The network lifetime will be improved by suitably reducing the requirement of power for connections. The objective of this paper is to develop a novel routing protocol for hybrid ad hoc networks. We proposed the enhanced version of ad hoc on-demand multipath distance vector (AOMDV) routing called power aware link stability routing (PALSR) protocol for energy conservation and establish a desired hybrid connection between MANET and internet. The proposed PALSR protocol uses a new metric to find the route with higher transmission rate, less latency and better stability. It checks bandwidth and delay constraint during route request and uses as well new mobility prediction mechanism to determine the stability of link during a path selection. We evaluate the performance of PALSR using NS-2.34 simulation tool and compare it with AOMDV protocol. The simulation results show that the performance of new routing protocol significantly improves the network performance by discovering the required path with minimal power and delay.

Keywords: power aware link stability routing; PALSR; ad hoc on-demand multipath distance vector; AOMDV; QoS; mobile ad hoc network; MANET; packet delivery ratio.


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G. Sudha Sadasivam is working as a Professor in CSE Department of PSG College of Technology. She has 20 years of teaching experience. She has published five books and 20 papers in referred journals. She has coordinated two AICTE-RPS projects in the areas of distributed computing. She is the Coordinator of PSG-Yahoo research in grid and cloud computing and Xurmo Research in social networking.

1 Introduction

The mobile ad hoc network (MANET) is a collection of infrastructure less mobile nodes that can be formed without need of a fixed infrastructure or centralised administration. Traditional routing protocols in ad hoc networks are classified into three groups such as proactive, reactive and hybrid. The table-driven routing protocol is proactive, it worked on distance vector-based or link state-based routing strategies. Examples of this class of ad hoc routing protocols are the destination-sequenced distance-vector (DSDV) (Perkins and Bhagwat, 1994) and optimised link state routing (OLSR) (Clausen et al., 2003). The drawback of this algorithm is to update the table frequently which consumes...
a large amount of memory, bandwidth and power. But, in the reactive routing protocol, each node does not need to maintain the routing table. When a source node is ready to send data, it initiates the route discovery procedure and maintains its routes only. The reactive routing protocol minimises the routing overhead and is also called on-demand approach. Examples of reactive routing protocols are the dynamic source routing (DSR) (Johnson et al., 2001), the ad hoc on-demand distance vector (AODV) routing is proposed by Perkins and Royer (1999) and the temporarily-ordered routing algorithm (TORA) (Park and Corson, 1997). The proposed protocols belong to this category of routing algorithms. The ad hoc on-demand multipath distance vector (AOMDV) protocol is a multipath extension of AODV. It provide link-disjoint, loop free and fault tolerance paths in AODV. By using the alternate paths, the packet loss and energy will be minimised that leads to improve the lifetime of the network. There is a challenge to provide end-to-end quality of service between a mobile device in a MANET and a host device in wired network. Gateway acts as a bridge between a MANET and the internet and all communication between the two networks take place through this gateway. The main goal of a QoS multipath routing protocol is to identify loop free paths from the source to the destination with the available resources to meet the QoS requirements of the desired service. The advantages are better network utilisation, network resilience to failures and efficient usage of bandwidth.

The major contribution of this work is to introduce energy efficient and modified versions of AOMDV routing protocols for hybrid network. We provide solutions to multi constraint optimisation routing problem (energy, delay and bandwidth-constraint). The link stability of path is predicated from link expiration time (LET) (Su et al., 2001) and minimum drain rate (DR) (Kim et al., 2003) in power aware link stability routing (PALSR). These metrics are used to maintain a balance between mobility and energy constraint in ad hoc networks.

The paper is organised as follows: Section 2 provides more details on the above prior work. Section 3 briefly details the network model for proposed routing protocol. Section 4 illustrates example network for QoS routing in hybrid scenario. Section 5 discusses the existing and proposed routing protocol. Section 6 gives the details of mobility model, energy model and traffic model for simulation and performance metrics for QoS parameters. Section 7 compares the performance of AOMDV and PALSR. Finally, Section 8 concludes the paper.

2 Related works
The latest research work on routing is mainly focused on stability of the path, impact of path selection criteria and alternate or back-up routing for energy efficiency and load balancing. The multipath with load balancing technique is mainly implemented in Marina and Das (2001); they proposed a loop free and link-disjoint multipath routing protocol (AOMDV). The performance of multipath routing was compared with single path routing protocol and the merits are listed out in Nasipuri et al. (2001) and Das et al. (2000). In many QoS routing protocol considers only one metric such as delay (Mostafa Mostafavi et al., 2010), bandwidth (Leng et al., 2009) and energy (Maleki et al., 2002). The PALSR considers multiple constraints such as delay, bandwidth, link stability ratio (LSR) (ratio of LET and minimum DR). The idea of mobility prediction is introduced in Su et al. (2001). The minimum DR (Kim et al., 2003) is the metric that measures the energy dissipation rate in a given node. A number of power aware research works have been presented in Wang (2010), Rishiwal et al. (2009), Qin (2011), and Zheng and Kravats (2005). Energy conservation in ad hoc network is discussed in Chang and Tassiulas (2000), Singh et al. (1998), Feeney (2001) and Toh (2001) gives a brief introduction about different power aware routing. The objective of minimum total transmission power routing (MTPR) (Toh, 2001) is to minimise the total transmission power consumption of all nodes in the network. It selects a route with more hops than the min-hop path, which involves more nodes that increase the end-to-end delay. The MTPR does not consider the remaining power of nodes, so the lifetime of each node cannot be extended successfully. The residual battery power capacity of nodes is taken as operative metric for the min-max battery cost routing (MMBCR) (Toh, 2001). It chooses the route with high residual capacity than the nodes with low residual capacity. The lifetime of nodes is extended in the MMBCR scheme but it does not provide guarantee that the total transmission power is minimised over a chosen route. The conditional max-min battery capacity routing (CMMBCR) (Toh, 2001) considers both the total transmission energy consumption of routes and the remaining power of nodes. But, it does not provide a guarantee that the nodes with high remaining power will survive without power breakage even when heavy traffic is passing through the node. Romdhani and Bohnet (2004) proposed adaptive routing mechanism and the congestion information is obtained from a computed cost that depends mainly on the energy consumption speed and the candidate protocol for this technique is AODV. The different power aware routing protocols are implemented for energy consumption by using DSR, OLSR and AOMDV for MANET in Kunz (2008), Luo et al. (2006), Liu et al. (2008), and Upadhyayaya and Gandhi (2010). The above protocols are based on homogeneous nodes and hence are not suitable for our hybrid nodes with heterogeneous link characteristics. Our proposed protocols differ from other multipath routing protocols because these two protocols have been developed for hybrid nodes with heterogeneous link characteristics. Majumder and Sarkar (2010), Santhi and Sudha Sadhasivam (2011) discuss the techniques in hybrid network and their implementation using DSR and AODV protocols. But we consider AOMDV protocol for implementing hybrid ad hoc networks.
3 Network model

3.1 Problem definition

A heterogeneous network is represented by a directed graph $G = (V, E, D, B, L)$. Where $V$ is the set of wired and wireless nodes and $E$ is the set of links between different networks. Each link($i, j$) $\in E$ is associated with a primary cost parameter $c(i, j)$ and energy $e_{ij}$ and delay $d_{ij}$ are additive QoS metrics and bandwidth $b_{ij}$ is concave metric for multiple path $P = 1, 2, \ldots, p$. The problem is to find a shortest path from source to destination with minimum energy.

- A heterogeneous network is a collection of wired, wireless and mobile networks. It is denoted as $N = (N_1, N_2, N_3, \ldots, N_n)$. $N$ represents the heterogeneous network and $N_1, N_2, \ldots, N_n$ may be wired, wireless and mobile node.
- Let $N$ be the set of nodes in the network and $N_i$ be the neighbour set of node $i$, where, $N_i = \{N - S\}$. $S$ is the source node. Let $J$ be the set of nodes from which node $i$ receives the route request (RREQ) packet. Thus, $R = N_i - J$, is the set of nodes to which node $i$ forwards the RREQ packet.
- Multiple path is denoted as $P$. $P = P_1, P_2, \ldots, P_n$, $n$ is a number of paths. Message passed over this multiple paths and the load is shared by various links between source and destination pairs.
- The set $R_i = R_1, R_2, R_3, \ldots, R_n$ represents the distribution of the load across the set of the resources. Total traffic sent from the source is $R = \Sigma R_i$.

3.2 Link stability model

We consider two metrics to measure link and node stability such as LET and energy drain rate (EDR), respectively. The LSR is the combination of LET and EDR, the stability of the entire path will be maintained by using this metric.

3.2.1 Link expiration time

The mobility factor is proposed as LET from Su et al. (2001), it used to identify the duration of the link will be alive. The velocity and direction of the movement is constant. The position of node $i$ and node $j$ is denoted as $x_i$ and $x_j$, the velocity and direction of node $i$ and node $j$ is denoted as $(v_i, \theta_i)$ and $(v_j, \theta_j)$ $(0 \leqslant \theta_i, \theta_j < 2\pi)$, respectively.

The LET is denoted as

\[
\text{LET} = \frac{\sqrt{(a^2 + c^2)b^2 - (ad - bc)^2}}{(a^2 + c^2)}
\]

where

- $a = v_i \cos \theta_i - v_j \cos \theta_j$
- $b = x_i - x_j$
- $c = v_i \sin \theta_i - v_j \sin \theta_j$

The motion parameters are exchanged among nodes at regular time intervals through global positioning system (GPS) clock (Kaplan, 1996). If the velocity and direction of node $i$ and node $j$ will be $v_i = v_j$ and $\theta_i = \theta_j$ then the LET of two nodes become $\propto$.

3.2.2 Energy drain rate

The energy-based routing algorithms send large amount of data with maximum energy levels that leads to depletion of battery power at very early stage in higher energy levels. The nodes lose some of it energy due to overhearing of the neighbouring nodes. In this situation, power is lost even if no data is being sent through it. This problem is solved by using DR and it is defined as a metric for energy dissipation rate in a given node. Total energy consumption is calculated in every $T$ sec by every node and the DR is measured by exponentially averaging the values of previous and newly calculated values.

\[
DR_i = \alpha DR_{old} + (1 - \alpha)DR_{new}
\]

where $\alpha$ is selected between 0 and 1 that gives higher priority to updated information. If the DR is higher, then the node is faster to deplete its energy.

The LSR is measured from LET and DR and it is denoted as

\[
\text{LSR} = \frac{\text{Link expiration time}}{\text{Drain rate}}
\]

3.3 QoS formulation

The QoS constraints for the source to destination pair are $D_{th}$, $B_{th}$, $E_{th}$, $\text{LSR}_{th}$, we need discover the QoS routing for the flows and minimise the maximal load of nodes, that is, the sum of bandwidth and delay requirement for passing them. Our solution takes into account three QoS parameters, the bandwidth $B$, the transfer delay $D$, and the LSR. The latter represents the estimated delay, bandwidth and time during which the communication between the two nodes forming the link is always maintained.

We thus associate to every link $(v_i, v_j)$ a triplet, $B(v_i, v_j)$, $D(v_i, v_j)$ and $\text{LSR}(v_i, v_j)$.

The optimal path is selected from source $s$ to destination $d$ pair by satisfying the following condition with bandwidth constraint $B_{th}$, delay constraint $D_{th}$ and energy constraint $\text{LSR}_{th}$.

\[
\sum_{i,j} B_{ij} \geq B_{th} \quad \text{(or)} \quad B(P_k) \geq B_{th}
\]

\[
\sum_{i,j} D_{ij} \leq D_{th} \quad \text{(or)} \quad D(P_k) \leq D_{th}
\]

\[
\sum_{i,j} E_{ij} \leq E_{th} \quad \text{(or)} \quad E(P_k) \leq E_{th}
\]

\[
\sum_{i,j} \text{LSR}_{ij} \geq \text{LSR}_{th} \quad \text{(or)} \quad \text{LSR}(P_k) \geq \text{LSR}_{th}
\]
The two sets of source to destination path are denoted by P1, P2 and multipath routing select node-disjoint paths. The equation for node disjoint is

\[ N(P1) \cap N(P2) = \emptyset \cup V(P1) \cap V(P2) = \{s, t\} \]  

(8)

The cumulative sum of bandwidth of node disjoint paths P1 and P2 is greater than threshold value.

\[ B(P1) + B(P2) \geq B_{th} \]  

(9)

The delay constraint follow the below formula

\[ D(P1) + D(P2) \leq D_{th} \]  

(10)

The energy constraint is given by the following formula

\[ LSR(P1) + LSR(P2) \geq LSR_{th} \]  

(11)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pt</td>
<td>Transmitted time</td>
</tr>
<tr>
<td>Etx</td>
<td>Transmitted energy</td>
</tr>
<tr>
<td>Erx</td>
<td>Received energy</td>
</tr>
<tr>
<td>Ptx</td>
<td>Transmitted power</td>
</tr>
<tr>
<td>Prx</td>
<td>Received power</td>
</tr>
<tr>
<td>Einit</td>
<td>Initial energy</td>
</tr>
<tr>
<td>Eres</td>
<td>Residual energy</td>
</tr>
<tr>
<td>Econs</td>
<td>Consumed energy</td>
</tr>
<tr>
<td>TEC</td>
<td>Total consumed energy</td>
</tr>
<tr>
<td>LET</td>
<td>Link expiration time</td>
</tr>
<tr>
<td>DR</td>
<td>Drain rate</td>
</tr>
<tr>
<td>LSR</td>
<td>Link stability ratio</td>
</tr>
</tbody>
</table>

Table 1  Notation for the network model

The bandwidth, delay and energy constraints of QoS multipath routing protocol select the optimal path from source to destination pair. If the above QoS constraints are satisfied then the data packet will be broadcast over the established link.

The above network model use the following notations described in Table 1.

4 Example QoS network

The network is represented by a graph G(V, E, D, B, L) where V is the set of wired and mobile nodes in the network and E is the set of links. We denote \((v_i, v_j) \in V\), the link is formed by the two nodes \(v_i\) and \(v_j\). Our solution takes into account three QoS parameters: the bandwidth B, the transfer delay D and the LSR. The latter represents the estimated time during which the communication between the two nodes forming the link is always maintained. Thus, to every link \((v_i, v_j)\) a triplet: \(B(v_i, v_j), D(v_i, v_j)\) and \(LSR(v_i, v_j)\) is associated. Figure 1 illustrates an example of this representation.

If the route discovery process starts then the source node constructs special RREQ packet and broadcasts it through network. Nodes B, F and C check their bandwidth and delay value equal to the QoS constraints. Let \(BW_{th}\) equal to 6 mbps, \(D_{th}\) is 25 s and \(LSR_{th}\) is equal to 20.

When the packet send, source node checks its neighbours (B, C, F) for their bandwidth and delay value. The node B and C are satisfied the condition but in node F bandwidth value is 4, it is less than the threshold value 6. Hence, the bandwidth constraint is not satisfied, the source node send the packets only to nodes B and C. No RREQ packet forward to node F. The delay, bandwidth and LSR field of RREQ updated and makes entry in its routing table. Node B now checks its neighbours, the QoS constraints are satisfied then it forward packet to node E and F. But here node E only is selected to forward the packet.

The delay is computed as the difference between two nodes receiving time. Every node is selected based on this condition. Finally, our algorithm selects the following paths.

Figure 1  Example network for QoS routing
Path 0→S→B→E→BS→I→D (Hop count = 5)
(Delay = 44 s) (Bandwidth = 42 mbps)

Path 1→S→C→D→BS→I→D (Hop count = 5)
(Delay = 46 s) (Bandwidth = 49 mbps)

Path 2→S→C→F→BS→I→D (Hop count = 5)
(Delay = 53 s) (Bandwidth = 43 mbps)

Three paths are selected in PALS protocol and the cumulative delay, bandwidth value are computed and updated in the routing table entries.

5 Routing protocols

The network is divided into three level, they are domain, cluster and nodes. The routing protocol uses hierarchy technique, the group of nodes use unique addressable entity from the top of the hierarchy. The three important advantages originating from this mechanism are the decline in the number of routing messages needed to converge, the reduction of the size on the route table (reducing the memory needed) and also the reduction of the convergence time.

This paper deals with two routing protocols in wireless domain such as AOMDV routing protocol, PALS protocol.

5.1 AOMDV routing protocol

AOMDV protocol is enhanced version of AODV ad hoc on-demand distance vector. It belongs to on-demand and reactive routing protocol of ad hoc wireless networks.

The main goal is to compute multiple loop-free and link-disjoint paths between source and destination pair. The merits of AOMDV are estimated in terms of increased packet delivery ratio, throughput and reduced average end-to-end delay and normalised control overhead. The average end-to-end delay is reduced by introducing multiple loop free paths in this scheme. In multiple routes, the destination contains list of the next-hops along with the corresponding hop counts in routing table entries. If all the next hops have the same sequence number, the advertised hop count is defined as the maximum hop count for all the paths. Route advertisement effectively sends to destination by using this hop count value. If any duplicate route advertisement received by a node then it forwards the packet thro alternate path to the destination. The loop freedom is ensured by selecting the alternate path for destination on the basis of the hop count value if it is less than the advertised hop count for that destination. The destination node sorts out all the paths by maximum hop count value. The best paths are selected and data forwarded through this path. In AOMDV, RREQ propagates from the source node to the destination for establish multiple reverse paths both at intermediate nodes as well as the destination. The corresponding multiple route reply (RREP) generates and traverses these reverse paths back to form multiple forward paths to the destination at the source and intermediate nodes. The major point in AOMDV is to provide alternate path for intermediate nodes also and it is useful for reducing route discovery frequency. It is classified into node-disjoint or link-disjoint route. In node-disjoint routes, duplicate RREQs cannot be immediately rejected. Because the reason is RREQ and RREP pair arriving through different neighbour of the source node in a node-disjoint path.

5.2 PALS protocol

The main goal of the proposed work is to find the optimal path through multiple node disjoint routes from source to a given destination. Also, it keeps track of the route bandwidth and delay which can be further used by the source to select the optimal routes. The LET and minimum DR are used to measure the link stability.

- LSR depends directly on mobility factor
- LSR depends inversely on the energy factor.

The LSR is the ratio of mobility and energy factor. It defines the degree of the stability of the link. The higher the value of LSR then the stability of the link will be the higher and also the duration of its existence is greater. Thus, a route having all the links with LSR > LSRth is the flexible. We choose the AOMDV protocol as a candidate protocol.

Modifications are made to the RREQ and RREP packets to enable the discovery of link stable node disjoint paths. The proposed scheme has three phases: route discovery, route selection and route maintenance.

The various phases are described as follows:

1. route discovery
2. route selection
3. route maintenance.

5.2.1 Route discovery

In route discovery procedure, the link stability routing protocol (PALS) builds a route between source to destination using a RREQ and RREP query cycle. When a source node wants to send a packet to destination for which it does not already have a route, it forwards a RREQ packet to all the neighbours across the network. The performance of PALS is improved by adding QoS parameters in RREQ packet, two additional fields are added in the RREQ header information such as bandwidth and energy constraints. The extended RREQ packet of PALS is shown in Figure 2.
In PALS R routing discovery process, the source node in the network sends the extended RREQ message to the destination node through a number of intermediate nodes. The data transmission in wireless network can be directly within one hop or through a number of intermediate nodes. The extended RREQ message contains the source and destination node IP address, advertised hop count value, timeout value, bandwidth of the link (bandwidth) and minimum energy value. If the computed bandwidth and minimal nodal energy is greater than the threshold value of bandwidth and energy only then the RREQ message is forwarded to the next neighbour node otherwise it is discarded. When the RREQ message arrives at next node, the bandwidth and minimal nodal energy is updated into the route list entries. The structure of routing table entries for AOMDV and PALS R are given in Table 2.

Table 2 Routing table entries for AOMDV and PALS R.

<table>
<thead>
<tr>
<th>AOMDV</th>
<th>PALS R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination address</td>
<td>Destination address</td>
</tr>
<tr>
<td>Sequence number</td>
<td>Sequence number</td>
</tr>
<tr>
<td>Advertised hopcount</td>
<td>Advertised hopcount</td>
</tr>
<tr>
<td>Route list</td>
<td>Route list</td>
</tr>
<tr>
<td>(nexthop1, hopcount1, Bandwidth1, Delay1, LSR1,…)</td>
<td>(nexthop1, hopcount1, Bandwidth1, Delay1, LSR1,…)</td>
</tr>
<tr>
<td>. . . .</td>
<td>. . . .</td>
</tr>
<tr>
<td>(nexthopn, hopcountn, Bandwidthn, Delayn, LSRn,…)</td>
<td>(nexthopn, hopcountn, Bandwidthn, Delayn, LSRn,…)</td>
</tr>
<tr>
<td>Time out</td>
<td>Time out</td>
</tr>
</tbody>
</table>

The residual energy is computed at every node in the network. This residual energy is compared with LSR field of RREQ packet. If this value is less than the LSR field, then it replaced by residual energy. While selecting the best path, the LSR should be kept as the lowest among all the nodes in this route. The reverse route to source node is set same as AOMDV protocol. Once the RREQ packet is received by the destination node, the node will produce RREP packet and sends it back to the source node. RREP packet also includes two additional fields bandwidth and delay. The RREP packet records the routing information from the source to destination. The duplicate packet ID is received by the destination node, then it responds with a maximum of three RREP packets to the source node.

The following algorithm illustrates the route discovery process.

Algorithm: Route discovery

Step 1 Source node S

   a) Creates the RREQ packet with field values set as
      \( SA = S, DA = D, Seq. No = I, TTL = T, Hops = H, BW = 0, LSR = 0, D = 0 \).
   b) Broad cast the RREQ packet to next neighbour node whose \( BW_{th} >= BW \) and \( D_{th} <= D \).

Step 2 If the intermediate node will receive the RREQ packet

   a) The delay is calculated by the difference between current node’s received time with previous node received time.
   b) Forward the RREQ packet to node 2
   c) Calculate LSR value from LET and DR
   d) This computed LSR value is compared with \( LSR_{th} \). The route is selected on the basis of \( LSR_{th} >= LSR \), \( BW_{th} >= BW \) and \( D_{th} <= D \). Otherwise the link between Node1 and Node2 is unavailable.
   e) If the above QoS constraints are satisfied then the link stability ratio, bandwidth and delay values are updated into the routing table.

Step 3 If the node receiving the RREQ packet in D, then the node D

   a) Generate the RREP packet for unicasting to source. The bandwidth, delay field of the RREP packet is updated with the cumulative bandwidth, delay of the path.
   b) D unicast all the node disjoint paths back to the source node S.

5.2.2 Route selection

When the RREQ receives at the neighbour node, it forwards a RREP packet back to the source. Otherwise, it rebroadcasts the RREQ. If they receive a processed RREQ, they discard the RREQ and do not forward it. If RREQ of multiple paths are received at source node, it is stored by the hop count value. In AOMDV the route is selected on the basis of minimum number of hops. But the PALS R protocol selects the best path by sorting multi-route in descending order of LSR and bandwidth. The data packets are forwarded using maximal bandwidth.

5.2.3 Route maintenance

In case the energy value is less than the threshold value LSR then link is broken, a route error (RERR) message is sent back to the previous node to indicate the route breakage. If node receives this RERR message, it informs to the source node then it starts route discovery procedure again.

6 Experimentation setup

In this section, we present the results from detailed simulation experiments carried out using the NS-2 simulation software. Before we discuss the results, we first describe the mobility models and the performance metrics used to evaluate the prediction schemes.

Wired-cum-wireless allows simulation using both wired and wireless nodes and mobile IP integrated into the wireless model. Base station is created which plays the role of a gateway for the wired, wireless domains and it is responsible for delivering packets into and out of the wireless domain. Table 3 gives the detail illustration of simulation setup and parameters used for experiment.
Table 3 Simulation parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulator</td>
<td>NS2</td>
</tr>
<tr>
<td>Routing protocols</td>
<td>AOMDV, PALSР</td>
</tr>
<tr>
<td>Simulation time (sec)</td>
<td>500</td>
</tr>
<tr>
<td>Simulation area</td>
<td>800 * 800</td>
</tr>
<tr>
<td>Number of wired nodes</td>
<td>10, 20</td>
</tr>
<tr>
<td>Number of mobile nodes</td>
<td>10, 20, 30, 40, 50</td>
</tr>
<tr>
<td>Transmission range (m)</td>
<td>250 m</td>
</tr>
<tr>
<td>Mobility model</td>
<td>Random way point</td>
</tr>
<tr>
<td>Maximum speed</td>
<td>10, 20, 30, 40, 50 m/sec</td>
</tr>
<tr>
<td>Pause time</td>
<td>10, 20, 30, 40, 50</td>
</tr>
<tr>
<td>Connection rate</td>
<td>5 packets /sec</td>
</tr>
<tr>
<td>Data payload</td>
<td>512</td>
</tr>
<tr>
<td>Traffic type</td>
<td>CBR</td>
</tr>
<tr>
<td>Initial energy</td>
<td>1,000 J</td>
</tr>
</tbody>
</table>

6.1 Mobility model

The mobility model for the simulation is random waypoint model in a rectangular field. The field configurations used is 1,000 m * 1,000 m field with 10 to 100 nodes. Each packet starts its transmission from random location to random destination with randomly chosen speed. After the destination is reached it select another random destination after a pause. The pause time affects the relative speed of the mobile.

6.2 Energy model

The energy model used the following transmission power, receiving power and idle power for simulation. It is illustrated in Table 4.

Table 4 Energy model

<table>
<thead>
<tr>
<th>Transmission power</th>
<th>Receiving power</th>
<th>Idle power</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4 W</td>
<td>1.0 W</td>
<td>0</td>
</tr>
</tbody>
</table>

6.3 Traffic model

Random traffic connection of transmission control protocol (TCP) and continuous bit rate (CBR) can be setup between mobile nodes using a traffic scenario generator script. The source to destination pairs is spread randomly over the mobile and fixed network. The number of clusters and the packet sending rate in each cluster is varied by change the traffic load and pause time.

6.4 Performance metrics

The performance comparisons have been done by using normalised routing overhead, packet delivery ratio, throughput, end-to-end delay and energy consumption. The definitions of the five metrics are given in the following sections.

6.4.1 Packet delivery fraction

It is calculated as the ratio between the total numbers of data packets received by the destination nodes to the number of data packets sent by the source nodes during the time period of the simulation

\[ \text{PDF} = \frac{\sum \text{Number of data packets received}}{\sum \text{Number of data packets sent}} \]  

6.4.2 Normalised routing overhead

It is defined as the ratio of the number of routing packets sent to the destination node and to the number of data packets actually received at source node.

\[ \text{NRO} = \frac{\sum \text{Number of routing packets sent}}{\sum \text{Number of data packets received}} \]  

6.4.3 Average throughput

The throughput is measured by the number of bytes in data packet received from source node or intermediate node against simulation time.

\[ \text{Throughput} = \frac{(\text{Number of bytes received} \times 8)}{(\text{Simulation time} \times 1,000)} \]  

6.4.4 Average end-end delay

The average end-to-end delay is calculated by the average time taken to transmit each packet of data from the source to the destination. Network congestion is indicated by higher end-to-end delays

\[ \text{Delay} = \frac{\sum \text{Time to packet arrive at destination} - \sum \text{Time to packet sent at source}}{\text{Total number of connection pairs}} \]  

6.4.5 Energy consumption

Consumed energy is defined as the ratio of global consumed energy to the number of data packets received.

- The transmitted energy is defined as
  \[ E_{tx} = \text{Transmitted power} \times \text{Transmission time} \]
- The received energy is calculated as
  \[ E_{rx} = \text{Received power} \times \text{Transmission time} \]
- Total consumed energy is estimated as
  \[ T_{\text{con}} = \text{No. of nodes} \times \text{Initial energy} - \text{Residual energy} \]

The less energy consumption by nodes extends the lifetime of the network.
7 Simulation results

We analyse the performance of PALSR over AOMDV, the number of nodes, mobility speed and pause time that is varied and compared with the help of QoS parameters discussed in Section 6. Number of nodes is varied from 10 to 50 wired and mobile nodes. The mobility speed is varied from 10 to 50 to know the impact of mobility of node in the network and pause time is taken from 100 to 500 second.

7.1 Varying speed

Figure 4 shows the results with varying mobility speeds. The sending rate of packet is 10 to 50 packets per second. The number of packet delivered in these two protocols decreases with the node speed.

**Figure 3** Performance with varying mobile speed, (a) packet delivery fraction (b) normalised routing overhead (c) throughput (d) average end-to-end delay (e) average energy consumed (see online version for colours)
Figures 3(a), 3(b) and 3(c) compare the performance of PALS with AOMDV in terms of the packet delivery fraction, normalised routing overhead and throughput. The throughput and PDF of PALS is higher than AOMDV because this proposed protocol maintains mobility through LSR and also can balance the load among different nodes by using this metric. So the lifetime of the network will be enhanced.

In Figures 3(d) and 3(e), respectively, show the average end-to-end delay and energy consumption for two ad hoc protocols. Average energy consumption represents the ratio of global consumed energy to the number of data packets received. The energy consumption and average end-to-end delay is minimised in PALS. The normalised routing overhead is illustrated in Figure 3(b). The RREQ and RREP packets add some fields to calculate transmitting power of nodes, which increases the size of control packets. So the routing overhead of new protocols are higher than AOMDV.
7.2 Varying nodes

Figure 4(a) compares the packet delivery ratio of two protocols in varying number of nodes. In the simulations, the PALSR performs best compared to AOMDV. In Figures 4(b) and 4(d), the trend of normalised routing overhead and average end-to-end delay is the same as that mentioned in previous subsection. The energy consumption and throughput is increased in PALSR protocol, it is illustrated in Figures 4(c) and 4(e).

7.3 Varying pause time

In this set of simulations, CBR is used to send packets and random way-point is adopted as mobility model. The pause time of nodes varies from 100 to 500 s. Figure 5 shows the energy consumption, average end-to-end delay, throughput, normalised routing overhead and throughput as the pause time of nodes changes. If the pause time of nodes is high then the stable network topology will be acquired and also the routing discovery and maintenance is simple. If the data packets can be persistently transmitted along the stable route then more energy will be saved. As is shown in Figures 5(a) to 5(e), the performance of PALSR routing scheme is better than AOMDV. Note that power aware routing scheme achieves low energy consumption because it considers the link stability to minimise the energy.

**Figure 5** Performance with varying pause time, (a) packet delivery fraction (b) normalised routing overhead (c) throughput (d) average end-to-end delay (e) energy consumed (see online version for colours)
From the above results in this section, it is proved that our protocols perform very well in both low and high mobility environments. It seems that PALSR significantly outperforms that of AOMDV in terms of throughput, packet delivery ratio, delay and energy consumption, two important metrics used to measure the stability of network. The routing control overhead incurred is higher for our protocol than AOMDV.

8 Conclusions

This paper is an attempt to present a novel energy aware multipath routing protocol (PALSR) for heterogeneous wired cum wireless network. The primary goal of this approach is that it dynamically adapts to varying network topology by monitoring the quality of each path from source to the destination and always using the optimal path for data transmission. The routes are selected in this technique by satisfying multi constraints (delay, bandwidth and energy) and stability of link. PALSR outperforms AOMDV in terms of throughput, average end-to-end delay, nodes lifetime, packet delivery ratio and energy consumption.

References


